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Fire Extinguishing Effectiveness Tests

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14. ABSTRACT

This report contains the results and preliminary conclusions provided by completion of the first half of the Fire Extinguishing Effectiveness Test program. Key results include the development of a process for evaluating alternative application methods and comparing them with existing technologies. Application of this approach has demonstrated the exceptional effectiveness of the Ultra High Pressure System (UHPS) on pool fires. This technology reduces the amount of agent required by more than 70%. Additional results on fires on gravel have shown that the Combined Agent Fire Fighting System (CAFFS) technology provides superior performance on fires where the film forming ability of AFFF is reduced and hot surface reignition dominates.
The report recommends development of an advanced demonstrator which combines UHPS and CAFFS technologies to prove the effectiveness of this system for future development of a light, lean and lethal deployable fire fighting vehicle.

15. SUBJECT TERMS

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Abstract

This report contains the results and preliminary conclusions provided by completion of the first half of the Fire Extinguishing Effectiveness Test program. Key results include the development of a process for evaluating alternative application methods and comparing them with existing technologies. Application of this approach has demonstrated the exceptional effectiveness of the Ultra High Pressure System (UHPS) on pool fires. This technology reduces the amount of agent required by more than 70%. Additional results on fires on gravel have shown that the Combined Agent Fire Fighting System (CAFFS) technology provides superior performance on fires where the film forming ability of AFFF is reduced and hot surface reignition dominates.

The report recommends development of an advanced demonstrator which combines UHPS and CAFFS technologies to prove the effectiveness of this system for future development of a light, lean and lethal deployable fire fighting vehicle.

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Executive Summary

The Fire Extinguishing Effectiveness Test (FEET) Program was developed to meet the need for a technically sound methodology to validate the effectiveness of new fire fighting technologies. This need was developed and validated by the Civil Engineering Fire Panel and the Fire Chief of the Air Force.

FEET testing has reached the series midpoint, with fires on water and gravel completed. The program has already provided key information essential to the development of new fire fighting vehicles for deployed Air Force applications.

The preliminary data show that for pool fires tested in the conventional fuel on water method Ultra High Pressure (UPHS) fire fighting technology reduces the quantity of AFFF solution required by more than 70%. Compressed Air Foam (CAF) and the Combined Agent Fire Fighting System (CAFFS) show a smaller but still significant decrease in agent requirement 40 to 50%. Additional tests conducted on gravel surfaces which reduce film forming effectiveness and enhance reignition hazards showed a specific advantage for the CAFFS technology when compared to all other technologies.

Based on these results, research should capitalize on best agent technologies by developing an advanced demonstration vehicle combining 500 to 600 gallons of water capacity, 300 gallons per minute of positive displacement pump flow (for UHP, CAF and CAFFS capability) and 500 to 1000 pounds of PKP (potassium bicarbonate base) dry chemical.

1 Introduction

This interim report provides test data collected on the Fire Extinguishment Effectiveness Tests (FEET) for the first half of the test series, which includes fires on water and gravel. In addition, preliminary analysis of the data is provided along with recommended equivalence values to quantitatively assess the fire extinguishing capability of the technologies described.

1.1 PURPOSE

The FEET Program was developed to meet the need for a technically sound methodology to validate the effectiveness of new fire fighting technologies. This need was developed and validated by the Civil Engineering Fire Panel and the Fire Chief of the Air Force.

1.2 BACKGROUND

1.2.1 Current Deployable Fire Trucks

The P-19 is the primary aircraft rescue and fire fighting vehicle (ARFF) deployed by the Air Force. Due to the size and weight of the vehicle, only one P-19 can be transported on a C-130. For initial deployments, this often translates to limited crash fire protection for the first aircraft flying in and out of the location. In addition to providing critical fire protection overseas, these vehicles are the mainstay of many CONUS bases. Gaps in state-side fire protection are often experienced when these vehicles are sent overseas. With the increase in overseas missions, these assets are becoming more critical. New ARFF vehicles being designed are expensive, complex and often exceed transport capabilities of the C-130. They often require special skill sets to maintain and operate these vehicles, which may be limited in a deployed environment.

Figure 1. P-19 Fire Truck.

1.2.2 New Fire Fighting Technologies

The Air Force Research Laboratory has been developing new technologies to improve the effectiveness of fire fighting equipment. With this improved effectiveness, smaller fire trucks can be built that have equal or greater fire fighting capabilities than the conventional systems currently installed on the P-19. These technologies include Compressed Air Foam (CAF), Combined Agent Fire Fighting System (CAFFS) and Ultra High Pressure System (UHPS).

The CAF system injected compressed air into the pressurized line between the pump and the nozzle. This resulted in a higher expansion ratio AFFF solution at the nozzle inlet. The resulting foam on the fire is less dense than foam from conventional systems, providing better cooling and better insulation between the fuel and the fire.

The CAFFS system injected compressed air foam, but added the benefits of dry chemical. A special nozzle was used that discharged the dry chemical through a central orifice. The compressed air foam discharged through an annular opening around the dry chemical orifice.

The CAF and CAFFS systems were represented by a modified P-27 fire truck. This truck is shown in Figure 2 operating in the CAFFS mode. It was equipped with an air compressor, a dry chemical system and a bumper turret. The compressed air foam and dry chemical systems was operated separately or together resulting in CAF or CAFFS operation.

Figure 2. CAFFS/CAF Waterous Fire Truck.

During the FEET series, tests were added using the AFRL Skid system for the CAF and CAFFS system. This skid, shown in Figure 3, operated at a much lower foam flow rate, offering the ability to investigate the effect of higher foam to dry chemical ratio.

Figure 3. AFRL CAF/CAFFS Skid System.

The UHPS system, shown in Figure 4, delivered AFFF solution at approximately 1500 psi. Operating at this pressure significantly changed the characteristics of the solution and its effect on the fire.

Figure 4. Ultra High Pressure System.

1.3 SCOPE

These tests were subject to the following limitations:

- Two-dimensional fires only.
- Turrets were used on all fires. No hand line fires were included.
- Vehicles were stationary during the fire.

- For CAFFS fires, both agents were discharged simultaneously and continuously.
- Tests were conducted on available equipment at flow rates that were within the capabilities of that equipment.
- Tests were conducted with the wind coming from the rear of the vehicle (+/-30 degrees) at speeds at 7 mph or less.

The key test variables were:

Surface

Fires were fought on the following surfaces:

- Water
- Gravel (1 ½ inch) with water approximately 1” below the surface
- Simulated unpaved surface, using soil or sod.
- Sacrificial hard surface

Tests were grouped sequentially by surface, since the surface could not be easily varied from test to test.

Flow and Area

Fires were fought on surface areas of 877, 3507, 5172 and 6644 square feet. The circles in Figure 5 show relative sizes of fires. During testing, the 6644 square feet size was determined inappropriate because the outside edge of the fire pit was at the water to gravel interface. The gravel at this edge held fuel in its irregularities, making the outside edge more difficult to extinguish than in the smaller fires. The smaller fires had a steel ring as a dam to contain the fuel. As a result, the largest fire size was reduced to 5172 square feet to allow use of a steel ring on the outer edge on the largest fire.

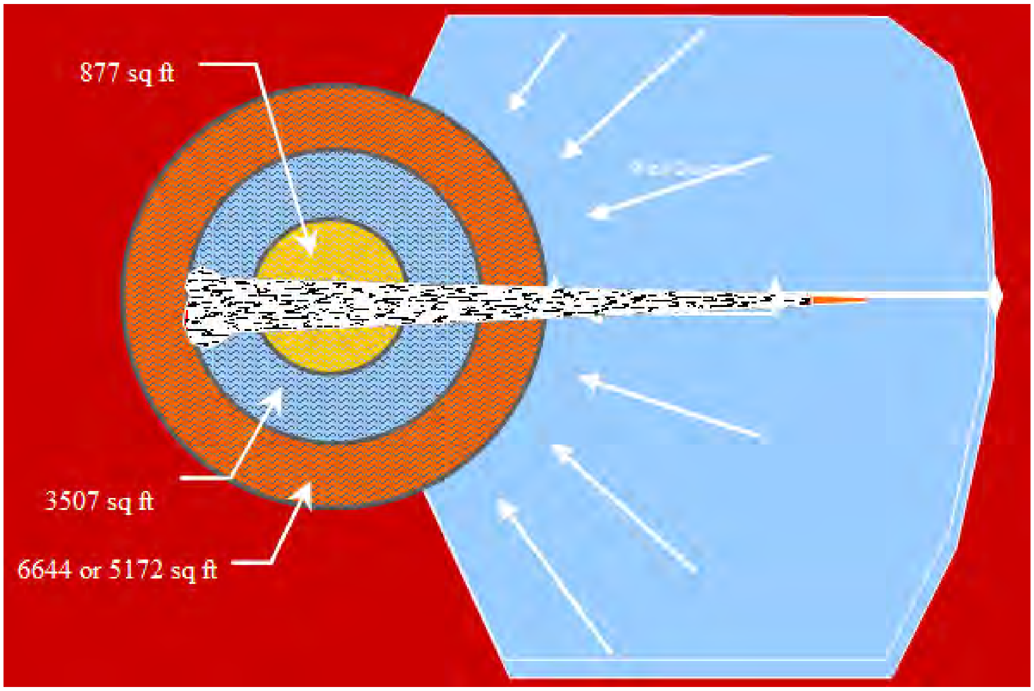

Figure 5. Fire Sizes.

After completion of the water tests, the smallest fires showed that the data was not useful due to excessive scatter. The time to extinguish was very rapid, making timing difficult. Minor variation on operator technique resulted in large variation in application rate. As a result, the 877 square foot fires were eliminated for fires on surfaces other than water.

Flow rates used depended on the capabilities of the equipment used to demonstrate a particular technology. Flow rates are:

Baseline AFFF/Water	250 gpm	500 gpm
CAF	125 gpm	220 gpm
CAFFS (foam/dry chem.)	125 gpm/3lb/sec	220 gpm/7.5 lb/sec
UHPS	70 gpm	100 gpm

Four test conditions that were not included in the test plan were added to clarify observations of the CAF and CAFFS data. These test conditions were adding 60 gpm of foam flow on the 3507 sq. ft. fires to the CAF and CAFFS systems on water and 877sq. ft. fires on gravel.

Five replicates were conducted of each combination of flow, area, surfaces and fire fighting technology. This resulted in a total of 380 tests, as shown in Table 1.

Table 1. Test Matrix

Application System		Baseline Water/AFFF		Compressed Air Foam			Combined Agent			Ultra High Pressure		Fires
Foam Flow (gpm)		250	500	60	125	220	60	125	220	70	100	
Surface	Area (sq.ft.)											
Water												
	877	5	5		5	5		5	5	5	5	40
	3507	5	5	5	5	5	5	5	5	5	5	50
	5172/6644	5	5		5	5		5	5	5	5	40
Gravel												0
	877			5			5					10
	3507	5	5		5	5		5	5	5	5	40
	5172	5	5		5	5		5	5	5	5	40
Soil/Sod												0
	3507	5	5		5	5		5	5	5	5	40
	5172	5	5		5	5		5	5	5	5	40
Concrete												
	3507	5	5		5	5		5	5	5	5	40
	5172	5	5		5	5		5	5	5	5	40
Total		45	45	10	45	45	10	45	45	45	45	380

1.4 Methods and Procedures

1.4.1 Test Sequence and Randomization

In a designed experiment, tests should be conducted with the levels of the main factors, (surface, area, flow rate and technology) mixed in a random order. This was not feasible in this experiment. Changing surfaces and fire sizes required excessive time and labor and could not be accomplished from test to test. Similarly, changing vehicles randomly could not be accomplished due to schedule concerns. Groups of tests were conducted with a single vehicle, usually within one day of tests. Flow rates were mixed, as were tests between CAF and CAFFS.

The fire fighters were randomly mixed throughout the test, however they were grouped by the individuals that were available during a particular time period. The four reserve firefighters conducted most of the tests. Three of these individuals were not available for a six week period, and other fire fighters were used. Occasionally, the AFRL/MLQD fire fighters participated in the tests throughout the entire series.

The first tests conducted were using the P-19, the CAF and CAFFS on water. The smallest fires were conducted first, progressing up in fire size with these three technologies. The UHPS system was still under development and was not included in the initial tests. Flow rates were varied randomly.

After completing the P-19, CAF and CAFFS tests on water and gravel, The UHPS was tested on water, then gravel. This was followed by tests using the AFRL CAF/CAFFS skid.

2 Instrumentation

Each of the fire fighting vehicles was instrumented and data were collected into spreadsheet files. The P-19, UHPS and CAF systems included pressure at the nozzle and foam solution flow measurements. The CAFFS system included these measurements and dry chemical pressure at the nozzle. All data were recorded at 0.1 second intervals. A switch was operated by the test conductor to provide an indication in the data file of the start of agent application and the time of extinguishment.

Two video cameras were used during testing. One camera was placed along side of the fire fighting system, while the other camera was placed in a position approximately 90 degrees away from the fire fighting vehicle.

2.1 Testing Procedures

Prior to starting a test, all fire fighting vehicles were checked out for normal operation including engines, pumps, nozzles, tanks and valves.

The CAF system was adjusted to provide expansion ratio of six to eight. A metering valve and a ball valve were installed to adjust the air flow rate to maintain this expansion ratio with either the high flow or low flow. By opening and closing the ball valve, the system provided proper air flow for the high flow or the low flow nozzle.

The Hydrochem™ nozzle used on the CAF and CAFFS tests was modified to maintain system pressure while operating at low flow. A more restrictive nozzle insert was installed for the low flow tests. This insert reduced the cross sectional area of the foam and dry chemical discharge. The original nozzle configuration was used for the high flow rate tests.

The UHPS system used the AFRL/MLQD designed nozzle shown in Figure 6. The high pressure nozzle was strapped on to the top of a Sidewinder nozzle. The Sidewinder provided the remote control capability, and did not flow agent. Two of these nozzles were used. The 100 gpm tests used a 0 308” diameter bore, while the 70 gpm tests used a 0.264” diameter bore.

Figure 6. UHPS Nozzle

Testing procedures for all fire fighting vehicles had certain common elements, which are described below.

1. Monitor weather conditions and weather forecasts. Tests were conducted when wind was less than 7 mph and in absence of precipitation.
2. Check fuel level in the tank, assuring that the fuel level indicator was positioned at the 1:30 clock position or higher.
3. Assure that the pit had the proper surface and ring size for the intended experiment. For water fires, assure that the water level covered all concrete and did not reach within 0.5” of the top of the containment ring. Gravel and soil/sod fires required that the surface was level.
4. Assure that permission and notification calls were made.
5. The fire fighting apparatus was placed in the upwind location. Other equipment was placed in appropriate locations around the fire fighting vehicle included:
    a. Data Acquisition trailer
    b. Backup fire fighting vehicle
    c. Pumper truck as needed
    d. Cameras
    e. Weather monitor, which included the directional wind measurements
6. The level of fire fighting agents was checked. The pumper truck was connected as required.

7. The data acquisition trailer was connected and computer system started. A flow test was conducted to verify that pressure and flow transducers were functioning properly.

8. Pump fuel into the pit. Fuel was added to achieve approximately ¼ inch depth over the entire surface. For fires on gravel, the fuel was distributed with a hose.

9. Assure that personnel were in required locations:

    a. Test conductor was at the data acquisition system

    b. Firefighter was at the test vehicle operator’s station

    c. Firefighter was in the backup vehicle

    d. Firefighter was ready to light

10. The data acquisition system and cameras were started.

11. Fire was lit.

12. Typically, a 30 second preburn time elapsed to get the pit fully involved. The test conductor provided a 10 second countdown.

13. The firefighter extinguished the fire within the ring. Fire outside the ring was left burning. The test conductor called “Fire Out”, terminating the test.

14. The backup vehicle extinguished any remaining fire.

15. The test conductor reviewed the test data.

16. On fires prior to #149, the pit was burned off after each fire and at the end of each day. On subsequent fires, approximately half the nominal fuel quantity was added when the pit was not burned off. No observable differences in the fires before or after test #149 were documented.

17. Agents were reloaded. For CAFFS fires, the quantity of dry chemical and the depth in the tank before and after refilling were recorded.

3 Results

This midterm report provides preliminary results for fires on water and gravel only. Upon completion of the test series, a final report will be presented that presents results from all four surfaces.

The behavior of fires on water and gravel, as well as the effectiveness of the different application technologies, were significantly different from each other. As a result, fires on each surface were treated as a separate experiment. The data from these two experiments were not intermingled, except in conclusions and recommendations.

3.1 Fires on Water

Data presented in this section was the result of 114 fires. Fires on water included all four fire sizes, except the UHPS system, which only was tested on the 3507 and 5172 square foot sizes. The complete data set is shown in Figure 7.

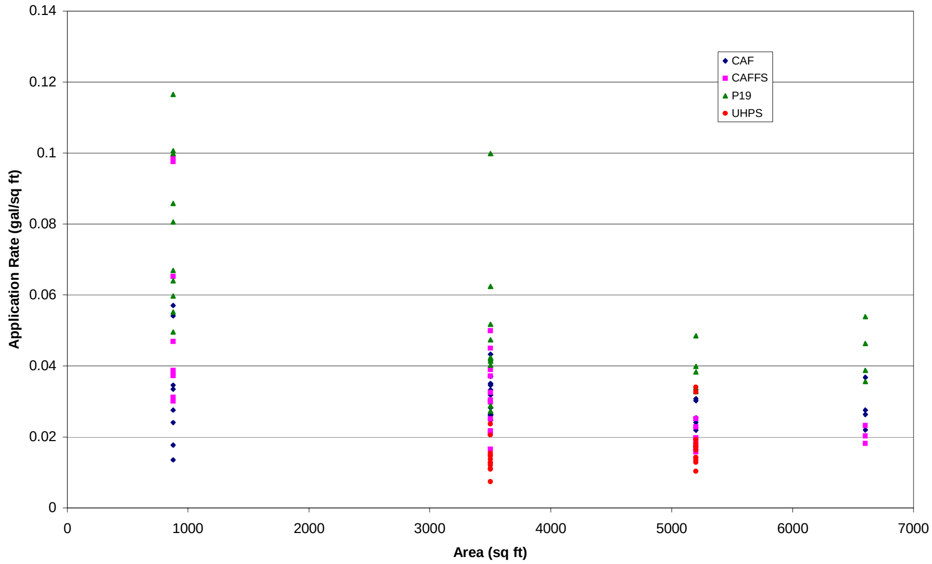

Figure 7. Application Rate for Fires on Water, All Data.

This shows application rate as a function of area for all technologies. The greatest scatter in the data occurred with the smallest fires. For this reason, the smallest size fires were eliminated.

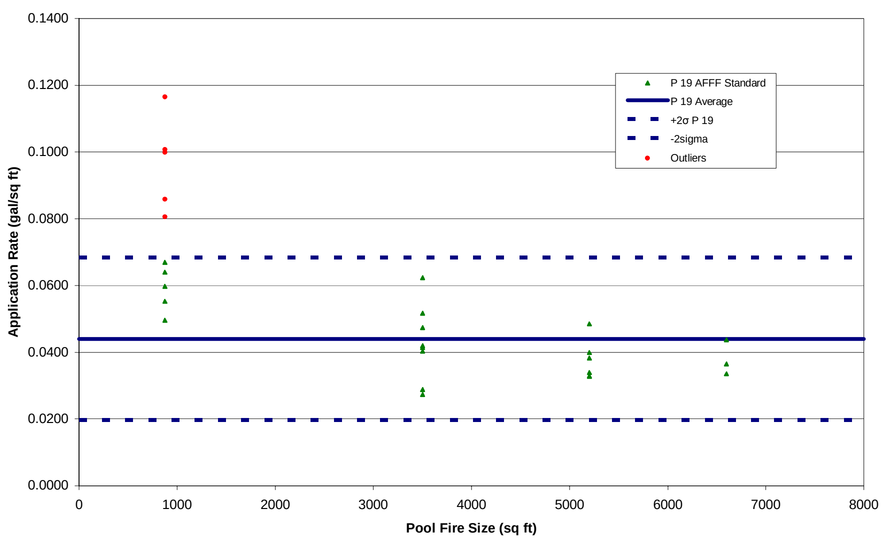

Figure 8. P-19 Application Rate for Fires on Water.

Figure 8 shows the application rate for P-19 fires on water. This plot shows horizontal lines for the mean value and the band of data that was within two standard deviations of the mean. This statistical information did not include the outliers, which was judged as not being valid data. Assuming that the data were normally distributed, 98% of the fires were extinguished using less than the mean plus two standard deviations. This value was represented by the upper dotted line. For the P-19, this means that 98% of fires on water used less than 0.068 gallons per square foot.

Outliers occurred for a number of reasons. The smallest fires, particularly with the highest flow rates were extinguished very rapidly, resulting in timing difficulties. The fastest extinguishment time for the P-19 on the smallest fire was 5.5 seconds. For this fire, a 1 second error in timing would result in 18% change in application rate. For practical reasons timing within one second was the maximum precision that was obtained.

Outliers also occurred because of adverse wind conditions. Occasionally, a cross wind, or even a head wind developed after the fire was lit. The fire was extinguished under these conditions; however the results usually indicated high agent application.

Outliers also occurred due to firefighter technique. This was most evident early in the testing as the firefighters gained experience and improved their technique.

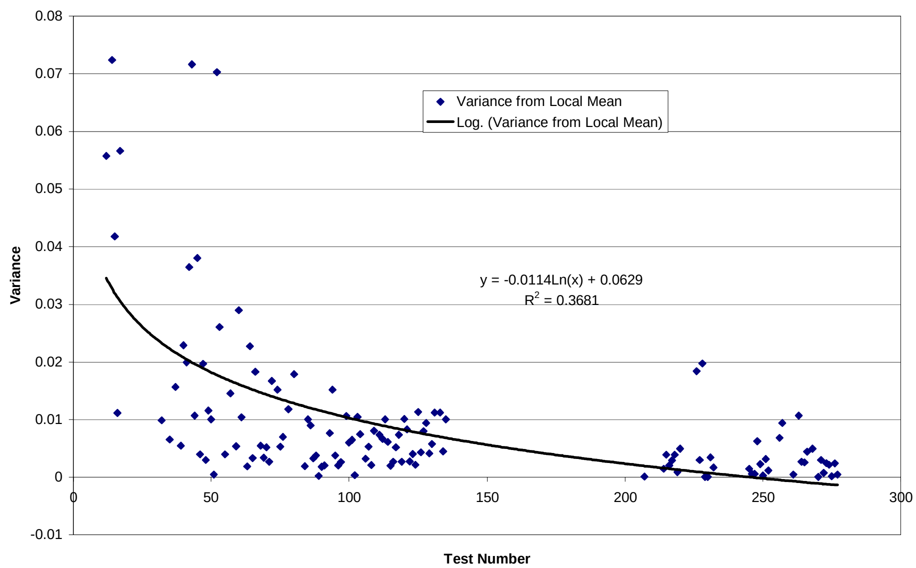

Figure 9. Effects of Fire Fighter Experience.

Figure 9 shows the improvement of the firefighters as they gained experience. This plot was accumulated from the fire on water data. The plot shows variance from the local mean as a function of test number. The local mean was the mean value for the technology being tested, as shown by the solid line in Figure 8 for the P-19. The gap in the middle of the plot was due to conducting gravel fires. This plot clearly shows that the firefighters became more consistent as they gained experience.

These firefighters initially used the “rain drop” technique during the early fires, as they were trained. As they fought fires, they learned that applying agent at the base of the fire was more effective and results in faster extinguishment. This probably reduced variance as they abandoned the raindrop technique.

Test technique improvement was also a factor when using joystick type controls. All systems, except the P-19 roof turret, used a joystick. Operation of these devices was not intuitive and required some practice. This was particularly true for the P-19 bumper turret. This control joy stick had very slow response, resulting in the operator having to anticipate its movement in order to minimize overshoot.

The application rate for fires on water using the CAF system is shown in Figure 10. Outliers were once again identified. Four out of five outliers were experienced on the smallest fires. For this system, the 98% confidence level was at 0.039gal/sq ft. This shows a significant improvement over the baseline P-19 system.

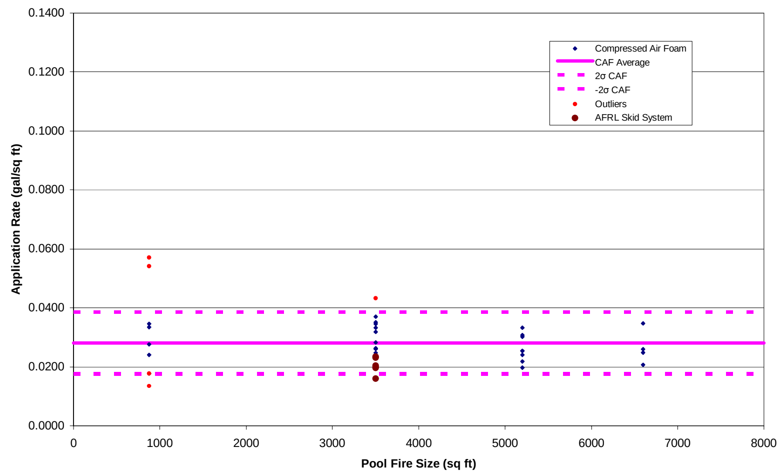

Figure 10. Compressed Air Foam Application Rate for Fires on Water.

Test results for CAFFS for fires on water are shown in Figure 11. Four outliers are identified and removed from the analysis. Three of which were from the smallest fire size. For this system, the 98% confidence level was at 0.046 gallons per square foot. This was slightly higher than the CAF value but significantly lower than the baseline P-19 system.

The application rates for dry chemical are shown in Figure 12 and summarized in Table 2. The dry chemical system did not distribute evenly. Although the system was operated at the same pressure (180 psi) for all tests, the flow rates varied significantly. Observation during testing suggested that the flow rates were not constant. Dry chemical tended to pack in the tank, causing lumps to form and the system to surge. This surging was more significant at the low flow rate, which was below the system normal operating conditions.

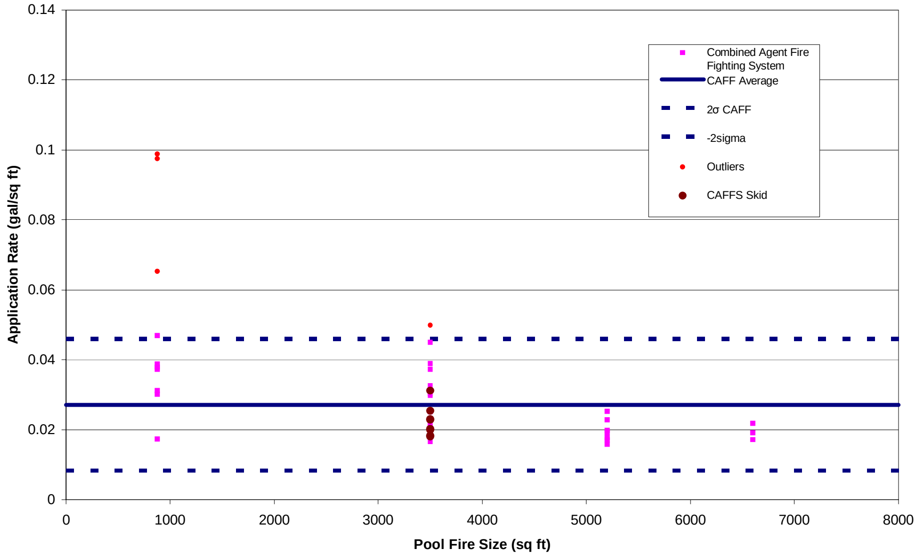

Figure 11 Combined Agent Firefighting System, Fires On Water

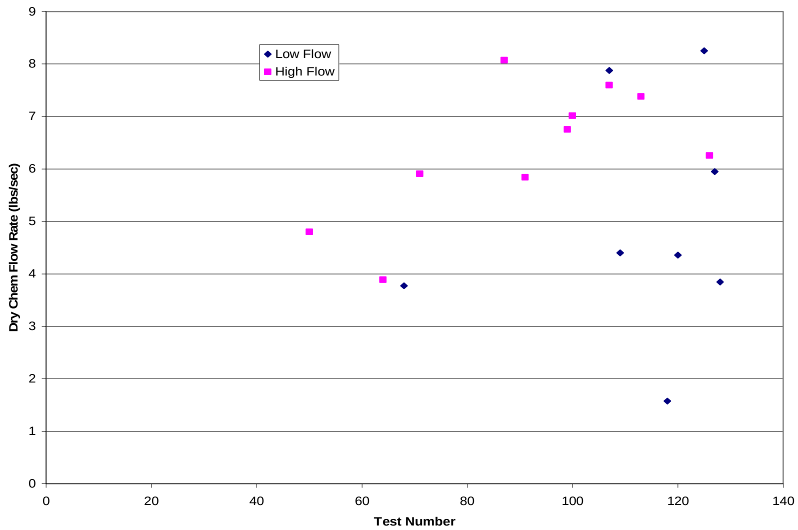

Figure 12. Dry Chemical Application Rates for Fires on Water.

Table 2. Dry Chemical Flow Rate Summary.		
	Low Flow	High Flow
Target	3	7.5
Mean	5	6.35
Standard Deviation	2.23	1.29

The CAFFS was expected to perform significantly better than the CAF system, based on previous experience with hand line experiments on the CAFFS skid. Since the Waterous system operated at higher foam solution flow rates, the ratio of dry chemical to foam was significantly lower when using the Waterous truck when compared to the skid. If the dry chemical flow rate were too low, then it would have little effect. As a result, the skid was included in the test matrix to evaluate CAFFS technology with a higher dry chemical to foam ratio. A comparison between the application rates for the Waterous truck and the skid is shown in Figure 13. The Waterous truck showed slightly better performance with the CAF, while the skid showed slightly better performance with CAFFS. Neither system showed significant difference between CAF and CAFFS. Consequently, the ratio of dry chemical to foam solution does not appear to have a significant effect of foam solution application rate when operating with a turret.

Test results for the UHPS fires on water are shown in Figure 14. Four outliers were identified, two at each of the fire sizes tested. The 877 square foot fires were not used with the UHPS system. The 98% confidence level was 0.0196 for this system, which was significantly lower than the other three fire fighting system.

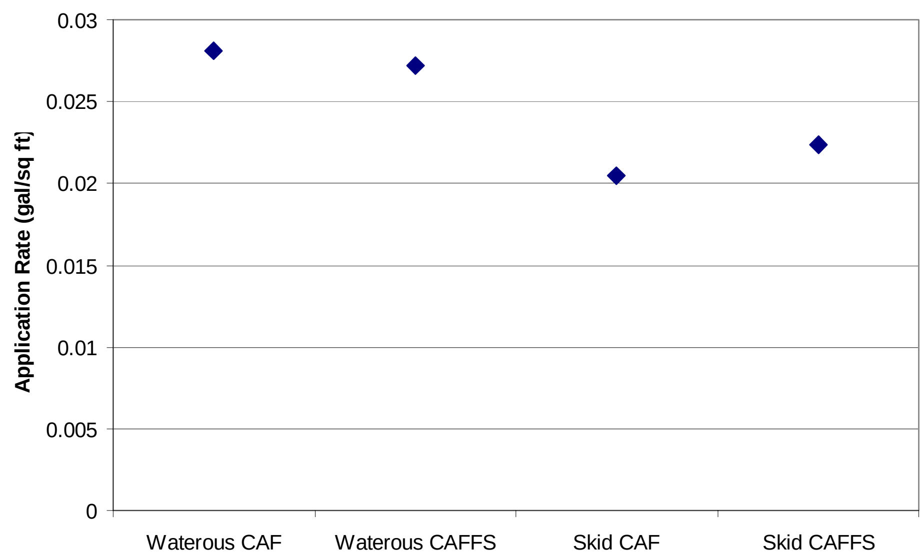

Figure 13. Waterous and Skid Application Rate Comparisons

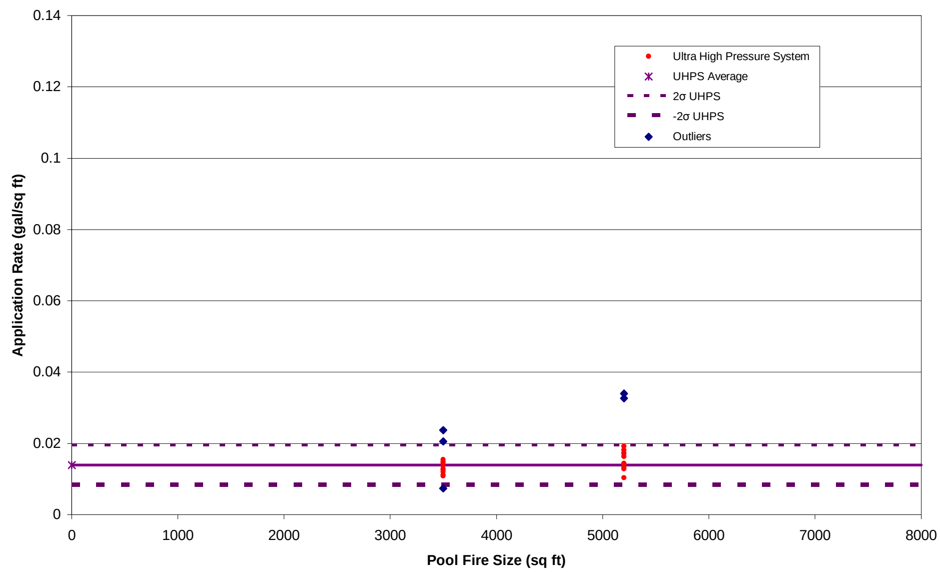

Figure 14. UHPS For Fires on Water.

A summary of all data for fires on water is shown in Figure 15. This shows the mean values for application rate and the error bars that represent two standard deviations for each technology. In addition, data extrapolated from NFPA 403 indicates that, for conventional AFFF application, fire fighting vehicles must provide 0.013 gallons per square foot of fire. This value was extrapolated to lower values for the fire fighting technologies tested. Using the 98% confidence values (the upper limit of the error bars) each technology was given an effectiveness rating compared to the P-19. This rating was multiplied by the 0.013 gallons per square foot to provide the rating for each new technology.

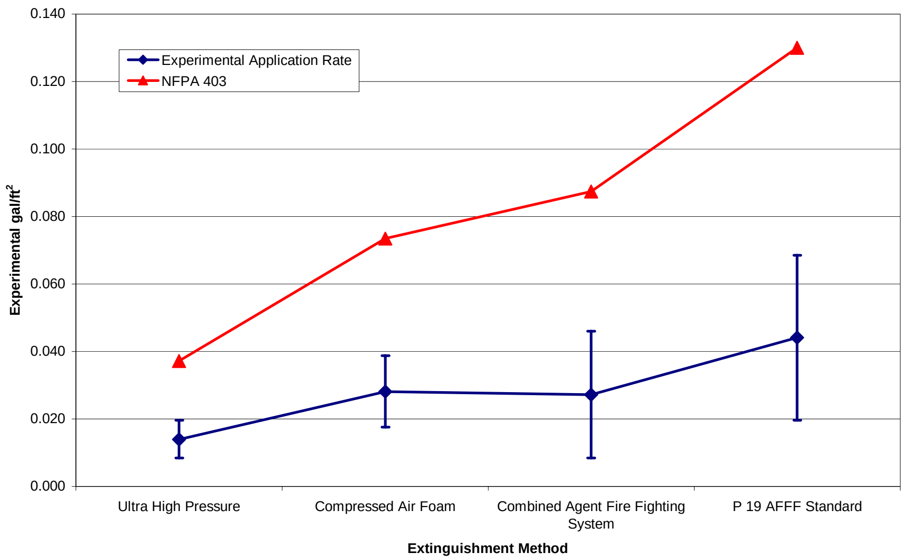

Figure 15. Summary, Fires on Water

Table 3 indicated that, for the same fire fighting effectiveness on water, the quantity of agent required was reduced by the quantitative agent requirement factors. This can result in a significantly smaller fire fighting vehicle.

Table 3. Technology Rating Factors for Fires on Water.

Extinguishing Method	Number of Tests	Quantitative Agent Requirement	NFPA 403 Critical Application Rate	Application Rate for Extinguishing	
	After Outliers	P 19 = 1.0	includes safety factor	Mean	2σ
Ultra High Pressure	20	0.286	0. 037	0.014	0.005
Compressed Air Foam	27	0.565	0. 073	0.028	0.011
Combined Agent Fire Fighting System	27	0.672	0. 087	0.027	0.0188
P 19 AFFF Standard	22	1.000	0. 130	0.044	0.0244

Another view of this data is shown if Figure 16, which presents the percent of fires extinguished as a function of application rate. This plot shows that the UHPS extinguished all fires at an application rate of 0.0193 gallons/sq ft or less. This is significantly lower than the most effective P-19 fire, which required 0.0273 gallons/sq ft. Application rates for the CAF and CAFFS were between these two extremes.

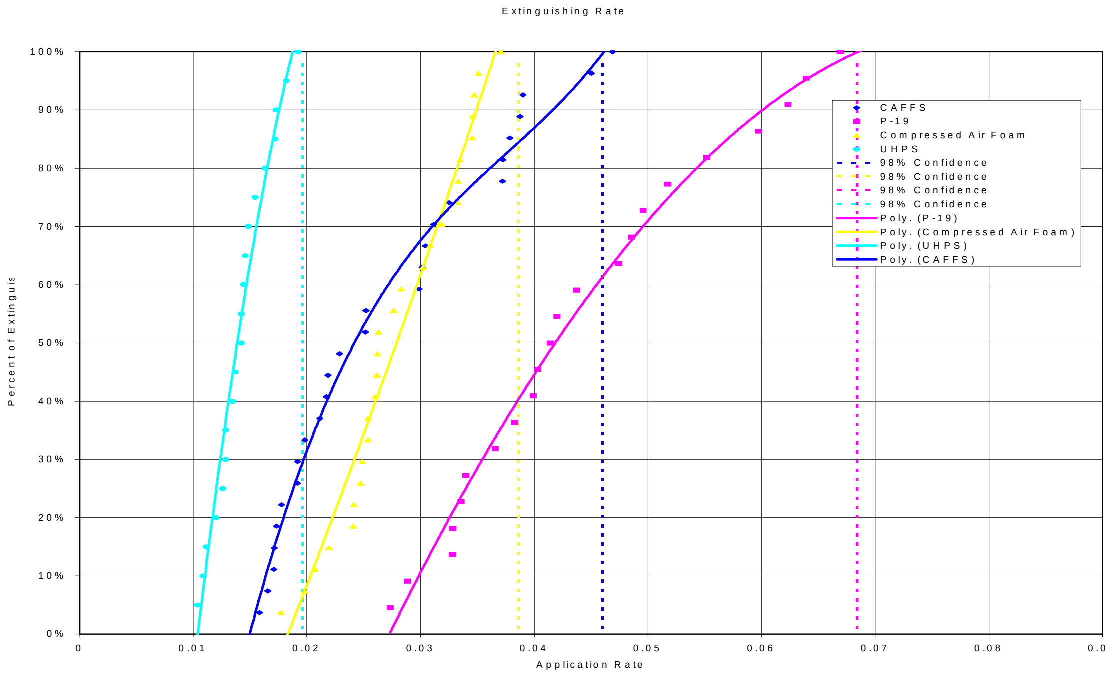

Figure 16. Percent of Extinguishment.

3.2 Fires on Gravel

Data in this section were the result of 98 fires. These tests, shown in Figure 17, were conducted on fire sizes of 877, 3507 and 5172 square feet. Only two fires were conducted on 877 square feet using the CAF/CAFFS skid. The small fire size was used because this device only contained 200 gallons of foam solution and was not replenished during the fire. The small fire size was used to minimize the possibility of running out of agent without extinguishment.

Data from the P-19, CAF, CAFFS and UHPS fires are shown in Figures 18 through 21. There are no outliers. Scatter in the data was approximately the same on both fire sizes. The mean and two standard deviation lines are shown on each plot.

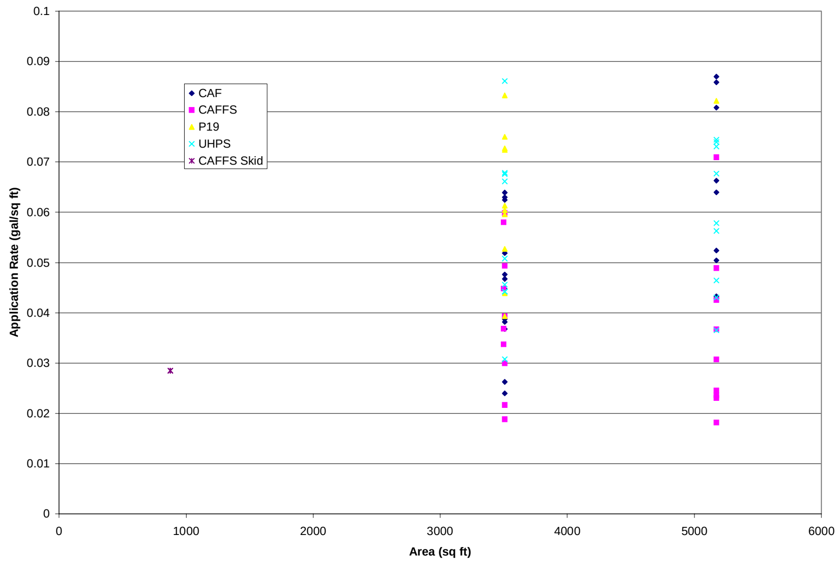

Figure 17. Application Rate for Fires on Gravel, All Fires

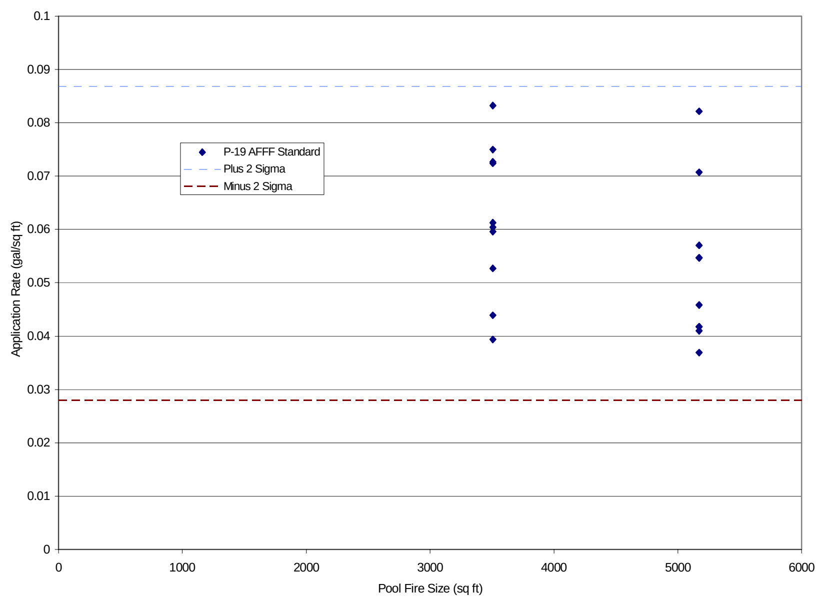

Figure 18. Application Rate for P-19 Fires on Gravel.

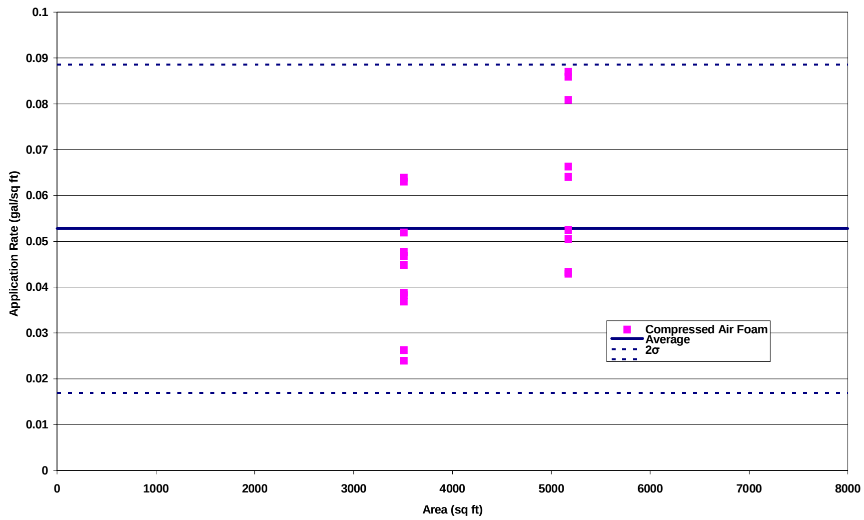

Figure 19. Application Rate for Compressed Air Foam Fires on Gravel.

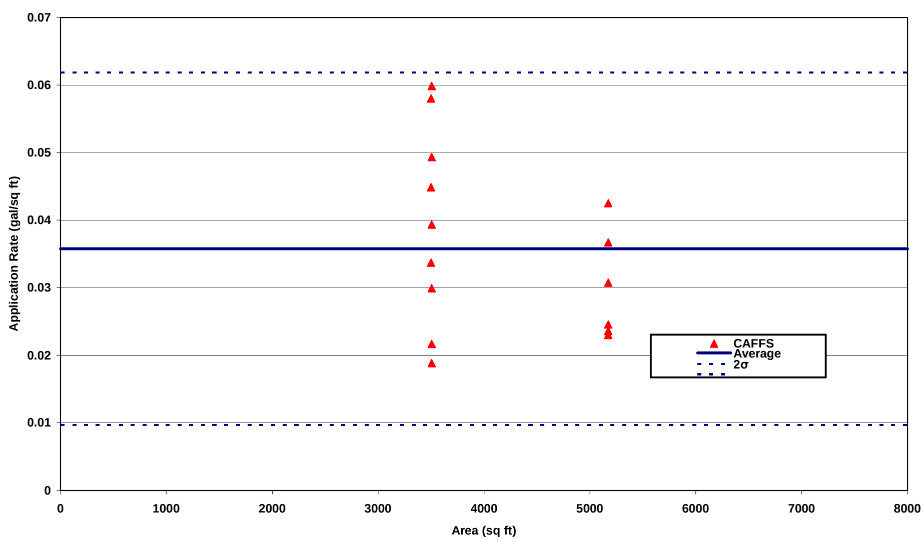

Figure 20. Application Rate for CAFFS Fires on Gravel.

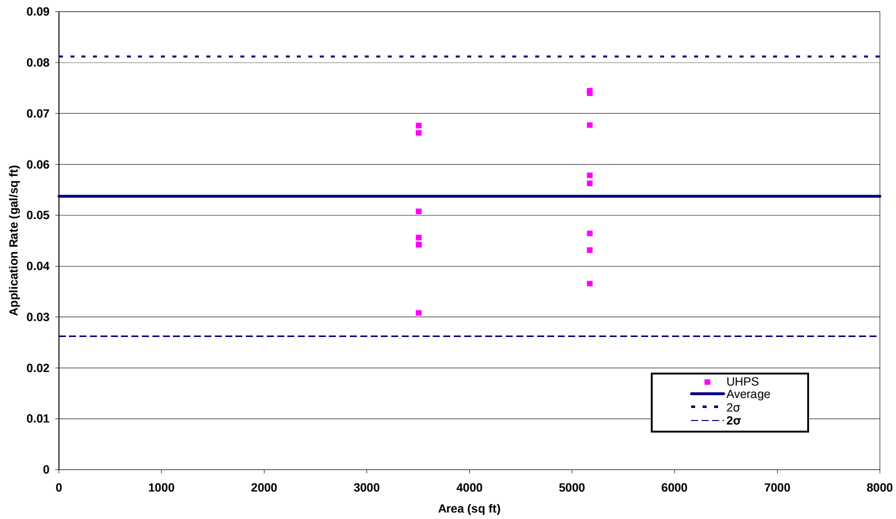

Figure 21. Application Rate for UHPS Fires on Gravel.

The data from all four fire types is summarized in Figure 22 and Table 4. The quantitative agent requirement and the extrapolated NFPA rating factor were computed in the same manner as for the fires on water. These data show that the CAF and UHPS show modest improvement over the P19 baseline. They used 0.0886 gal. /sq. ft. and 0.0812 gal. /sq. ft. of the foam solution compared to 0.0932 gal. /sq. ft. for the P-19. The CAFFS showed significant reduction in solution use, requiring 0.0687 gal/sq ft of the foam solution used by the baseline system. Clearly, the addition of dry chemical significantly reduced AFFF solution use.

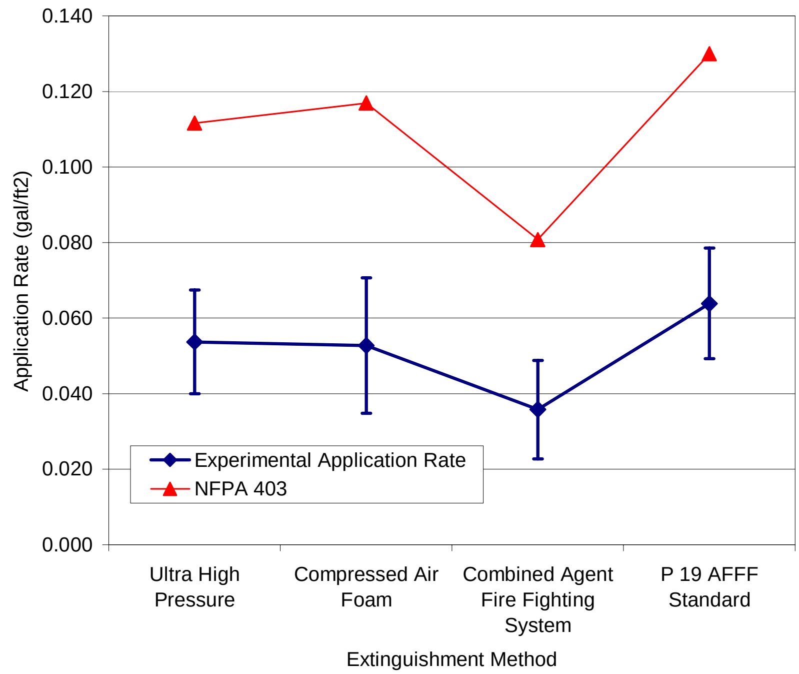

Figure 22. Summary for Fires on Gravel.

Table 4. Technology Rating Factors for Fires on Gravel.					
Extinguishing Method	Number of Tests	Quantitative Agent Requirement	Extrapolated NFPA 403	Experimental Application Rate	
	After Outliers	P19=1	Includes safety factor	Average	2σ
Ultra High Pressure	15	0.8587	0.1116	0.054	0.014
Compressed Air Foam	20	0.8998	0.1170	0.053	0.018
Combined Agent Fire Fighting System	15	0.6218	0.0808	0.036	0.013
P 19 AFFF Standard	11	1.0000	0.1300	0.064	0.015

4 Conclusions

The first half of FEET testing included test for fires on water and gravel using the P-19, CAF, CAFFS, and UHPS system. All test articles were tested on at least two fire sizes and two flow rates. At least five replicates of each test condition were conducted. After averaging the replicates, all of the new technologies extinguished the fire using lower quantities of agent than the baseline system. The characteristics of each fire fighting system were different on the two surfaces.

For fires on water, the UHPS system performed best, using only 28% of the agent used by the P-19 under similar conditions. The CAF system also showed exceptional performance, using 56%, while the CAFFS system used 67%. The AFRL CAF/CAFFS skid showed similar behavior, though the CAFFS did perform slightly better than CAF when testing the skid. Inclusion of the skid demonstrated that increasing the dry chemical to foam flow ratio did not substantially improve performance of the CAFFS system.

For fires on gravel, the CAFFS system performed best, using 62.% of the agent used by the P-19. The UHPS followed, using 85% and the CAF used 89%. The UHPS and CAF had difficulty with re-ignition of the fuel due to heat retained in the rocks. The fires were extinguished, but reignited and re-extinguished. This increased application rate. This problem was less significant with the CAFFS system because the dry chemical that settled on the hot rocks inhibited reignition.

Results of these tests show that a smaller, lighter fire truck can be built that carries less agent than the current system while providing equal or better fire fighting capabilities. This truck should include UHPS and CAFFS (which includes CAF) in order to maximize performance under all conditions. These results show that a 500 gallon water capacity truck would offer at worst equivalent performance to the P-19 and using the fuel on water data (similar to the NFPA standards) far superior performance equivalent to existing 1500 gallon trucks.

5 Recommendations

Complete testing through the soil/sod and hard surface tests. Reevaluate all technologies based on the completed test series.

Evaluate increased flow rates and improved nozzles for the UHPS to provide throw distances equivalent to the other technologies.

Capitalize on best agent technologies by developing an advanced demonstration vehicle combining 500 to 600 gallons of water capacity, 300 gallons per minute of positive displacement pump flow (for UHP, CAF and CAFFS capability) and 500 to 1000 pounds of PKP (potassium bicarbonate base) dry chemical.

Appendix 1. Test Data on Water

Experimental Data								Statistically Screened Data		
Method	Test Number	Flow Rate GPM	Extingushment Time Sec	90% time	Agent Used Gal	Area sqft	Application Rate gal/sq. ft.	Application Rate gal/sq. ft.	Screening Statistics	
CAF	57	89.0	8	6	11.86	877	0.014	outlier		
CAF	61	103.5	9	7	15.53	877	0.018	outlier		
CAF	121	116.6	53	36	103	5200	0.020	0.020		
CAF	114	220.6	31	25	114	5200	0.022	0.022		
CAF	111	202.3	43	30	145	6600	0.022	0.022		
CAF	123	166.8	45	38	125.1	5200	0.024	0.024		
CAF	55	50.8	25	12	21.15	877	0.024	0.024		
CAF	69	123.6	42	36	86.5	3500	0.025	0.025		
CAF	116	120.0	66		132	5200	0.025	0.025		
CAF	119	110.0	72	50	132	5200	0.025	0.025	CAF	
CAF	84	119.3	46	40	91.46	3500	0.026	0.026	mean	0.0287
CAF	63	196.7	28	20	91.78	3500	0.026	0.026	std dev σ	0.0049
CAF	90	122.7	45	35	92	3500	0.026	0.026	+2σ	0.0386
CAF	106	193.3	54	46	174	6600	0.026	0.026	-2σ	0.0189
CAF	108	113.8	96	60	182	6600	0.028	0.028	count	26
CAF	51	46.9	31	21	24.23	877	0.028	0.028		
CAF	89	204.8	29	22	99	3500	0.028	0.028		
CAF	124	80.6	117	60	157.2	5200	0.030	0.030		
CAF	122	106.8	90	55	160.2	5200	0.031	0.031		
CAF	88	128.7	52	44	111.5	3500	0.032	0.032		
CAF	117	122.1	85	60	173	5200	0.033	0.033		
CAF	70	211.9	33	27	116.53	3500	0.033	0.033		
CAF	59	88.1	20	15	29.35	877	0.033	0.033		
CAF	101	113.4	64	36	121	3500	0.035	0.035		
CAF	35	140.0	13	11	30.34	877	0.035	0.035		
CAF	76	124.9	59	52	122.82	3500	0.035	0.035		
CAF	112	214.4	68	45	243	6600	0.037	0.037		
CAF	86	222.5	35	24	129.8	3500	0.037	0.037		
CAF	74	216.4	42	28	151.5	3500	0.043	outlier		
CAF	53	219.2	13	11	47.5	877	0.054	outlier		
CAF	60	115.5	26	12	50.03	877	0.057	outlier		
CAFFS	125	117.6	36	42	82.3	5200	0.016	0.016		
CAFFS	99	193.3	15	18	58	3500	0.017	0.017		
CAFFS	120	113.5	36	47	88.89	5200	0.017	0.017		
CAFFS	32	76.0	10	12	15.19	877	0.017	0.017		
CAFFS	128	135.2	35	41	92.4	5200	0.018	0.018		
CAFFS	113	205.7	25	35	120	6600	0.018	0.018		
CAFFS	127	132.9	38	45	99.7	5200	0.019	0.019	CAFFS	
CAFFS	118	123.6	42	50	103	5200	0.020	0.020	mean	0.0258
CAFFS	109	118.2	55	68	134	6600	0.020	0.020	std dev σ	0.0079
CAFFS	100	170.8	22	26	74	3500	0.021	0.021	+2σ	0.0416
CAFFS	68	126.7	26	36	76	3500	0.022	0.022	-2σ	0.0100
CAFFS	126	209.8	22	34	118.9	5200	0.023	0.023	count	25
CAFFS	107	199.6	32	46	153	6600	0.023	0.023		

Appendix 1. Test Data on Water

Experimental Data								Statistically Screened Data		
Method	Test Number	Flow Rate GPM	Extingushment Time Sec	90% time	Agent Used Gal	Area sqft	Application Rate gal/sq. ft.	Application Rate gal/sq. ft.	Screening Statistics	
CAFFS	91	203.1	22	26	88	3500	0.025	0.025		
CAFFS	115	148.3	35	53	131	5200	0.025	0.025		
CAFFS	71	209.2	27	30	104.58	3500	0.030	0.030		
CAFFS	48	99.2		16	26.44	877	0.030	0.030		
CAFFS	87	199.7	23	32	106.5	3500	0.030	0.030		
CAFFS	46	78.1	19	21	27.33	877	0.031	0.031		
CAFFS	75	213.4	21	32	113.82	3500	0.033	0.033		
CAFFS	85	130.2	47	60	130.2	3500	0.037	0.037		
CAFFS	50	217.7		9	32.66	877	0.037	0.037		
CAFFS	44	221.3	8	9	33.2	877	0.038	0.038		
CAFFS	49	107.3		19	33.97	877	0.039	0.039		
CAFFS	78	117.0	104	70	136.5	3500	0.039	0.039		
CAFFS	80	124.4	52	76	157.6	3500	0.045	outlier		
CAFFS	47	117.5		21	41.12	877	0.047	outlier		
CAFFS	64	218.5		48	174.77	3500	0.050	outlier		
CAFFS	45	107.3	21	32	57.2	877	0.065	outlier		
CAFFS	52	119.3		43	85.5	877	0.097	outlier		
CAFFS	43	167.7	28	31	86.66	877	0.099	outlier		
P-19	72	478.4	12	10	95.68	3500	0.027	0.027		
P-19	94	505.0	12	10	101	3500	0.029	0.029		
P-19	131	445.0	23	20	170.6	5200	0.033	0.033		
P-19	133	250.0	41		170.8	5200	0.033	0.033		
P-19	135	500.0	20	18	176.7	5200	0.034	0.034		
P-19	103	522.2	27	25	235	6600	0.036	0.036		
P-19	130	259.7	46	40	199.1	5200	0.038	0.038		
P-19	104	251.8	61	46	256	6600	0.039	0.039	P-19	
P-19	129	254.2	49	40	207.6	5200	0.040	0.040	mean	0.0447
P-19	95	256.4	33	23	141	3500	0.040	0.040	std dev σ	0.0115
P-19	97	255.9	34	23	145	3500	0.041	0.041	+2σ	0.0677
P-19	96	518.8	17	13	147	3500	0.042	0.042	-2σ	0.0217
P-19	102	573.8	32	19	306	6600	0.046	0.046	count	22
P-19	65	553.0	18	14	165.89	3500	0.047	0.047		
P-19	134	250.0	58	50	252.5	5200	0.049	0.049		
P-19	39	260.8	10	9	43.47	877	0.050	0.050		
P-19	93	252.6	43	30	181	3500	0.052	0.052		
P-19	16	528.0	5.5	4.5	48.4	877	0.055	0.055		
P-19	37	261.9	12	9	52.38	877	0.060	0.060		
P-19	66	251.7	52	35	218.14	3500	0.062	0.062		
P-19	41	517.7	6.5	5	56.08	877	0.064	0.064		
P-19	40	220.1	16	10	58.7	877	0.067	0.067		
P-19	42	529.7	8	6	70.62	877	0.081	outlier		
P-19	15	531.3	8.5	7.5	75.27	877	0.086	outlier		
P-19	12	525.2	10	9	87.54	877	0.100	outlier		
P-19	17	264.8	20	19	88.28	877	0.101	outlier		
P-19	14	255.4	24	21	102.15	877	0.116	outlier		

Appendix 1. Test Data on Water

Experimental Data								Statistically Screened Data		
Method	Test Number	Flow Rate GPM	Extingushment Time Sec	90% time	Agent Used Gal	Area sqft	Application Rate gal/sq. ft.	Application Rate gal/sq. ft.	Screening Statistics	
UHPS	256	97.5	16	14	26	3500	0.007	outlier		
UHPS	215	87.4	37	30	53.9	5200	0.010	0.010		
UHPS	231	67.1	34	30	38	3500	0.011	0.011		
UHPS	251	68.8	34		39	3500	0.011	0.011		
UHPS	249	68.1	37		42	3500	0.012	0.012		
UHPS	232	67.7	39		44	3500	0.013	0.013		
UHPS	214	97.8	41	25	66.8	5200	0.013	0.013		
UHPS	245	93.1	29	25	45	3500	0.013	0.013		
UHPS	219	97.5	43	35	69.9	5200	0.013	0.013		
UHPS	246	90.0	32	28	48	3500	0.014	0.014	UHPS	
UHPS	229	72.8	61	49	74	5200	0.014	0.014	mean	0.0143
UHPS	230	71.6	62	50	74	5200	0.014	0.014	std dev σ	0.0024
UHPS	207	100.0	45	20	75	5200	0.014	0.014	+2σ	0.0192
UHPS	250	71.2	43		51	3500	0.015	0.015	-2σ	0.0094
UHPS	247	97.5	32	26	52	3500	0.015	0.015	count	20
UHPS	252	68.9	47		54	3500	0.015	0.015		
UHPS	216	98.0	52	40	84.9	5200	0.016	0.016		
UHPS	217	95.8	56	40	89.4	5200	0.017	0.017		
UHPS	227	72.9	74	60	89.9	5200	0.017	0.017		
UHPS	218	97.9	58	45	94.6	5200	0.018	0.018		
UHPS	220	66.7	90	50	100	5200	0.019	0.019		
UHPS	248	66.4	65		71.9	3500	0.021	outlier		
UHPS	257	103.8	48	34	83	3500	0.024	outlier		
UHPS	226	75.6	135	90	170	5200	0.033	outlier		
UHPS	228	70.8	150	120	177	5200	0.034	outlier		

Appendix 2. Test Data on Gravel

Experimental Data								Statistically Screened Data		
Method	Test Number	Flow Rate GPM	Extingushment Time Sec	90% time	Agent Used Gal	Area sqft	Application Rate gal/sq. ft.	Application Rate gal/sq. ft.	Screening Statistics	
CAF	136	112	45	30	84	3507	0.024	0.024		
CAF	149	212	26	22	92	3507	0.026	0.026		
CAF	152	123	63	54	129	3507	0.037	0.037		
CAF	148	217	37	26	134	3507	0.038	0.038		
CAF	158	240	34	25	136	3507	0.039	0.039		
CAF	194	226	59	33	222	5172	0.043	0.043		
CAF	191	122	110	37	224	5172	0.043	0.043		
CAF	147	224	42	37	157	3507	0.045	0.045		
CAF	151	129	76	57	164	3507	0.047	0.047	CAF	
CAF	137	124	81	62	167	3507	0.048	0.048	mean	0.0471
CAF	184	131	120	60	261	5172	0.050	0.050	std dev σ	0.0125
CAF	157	210	52	26	182	3507	0.052	0.052	+2σ	0.0722
CAF	169	171	95	44	271	5172	0.052	0.052	-2σ	0.0221
CAF	150	122	109	80	221	3507	0.063	0.063	count	17
CAF	138	164	82	55	224	3507	0.064	0.064		
CAF	188	223	89	41	331	5172	0.064	0.064		
CAF	199	189	109	43	343	5172	0.066	0.066		
CAF	198	173	145	53	418	5172	0.081	outlier		
CAF	187	215	124	55	444	5172	0.086	outlier		
CAF	196	172	157	62	450	5172	0.087	outlier		
CAFFS	153	104	35	38	66	3507	0.019	0.019		
CAFFS	145	157	25	29	76	3507	0.022	0.022		
CAFFS	185	143	19	50	119	5172	0.023	0.023		
CAFFS	190	203	20	36	122	5172	0.024	0.024		
CAFFS	192	218	20	35	127	5172	0.025	0.025		
CAFFS	146	197	27	32	105	3507	0.030	0.030	CAFFS	
CAFFS	200	145	32	66	159	5172	0.031	0.031	mean	0.0358
CAFFS	141	104	48	68	118	3500	0.034	0.034	std dev σ	0.0131
CAFFS	189	204	19	56	190	5172	0.037	0.037	+2σ	0.0619
CAFFS	155	193	38	43	138	3507	0.039	0.039	-2σ	0.0097
CAFFS	186	228	27	58	220	5172	0.043	0.043	count	15
CAFFS	140	121	65	78	157	3500	0.045	0.045		
CAFFS	154	118	78	88	173	3507	0.049	0.049		
CAFFS	139	214	50	57	203	3500	0.058	0.058		
CAFFS	156	203	45	62	210	3507	0.060	0.060		
CAFFS	201	151	40	146	367	5172	0.071	outlier		
P-19	162	251	33	16	138	3507	0.039	0.039		
P-19	160	250	37	13	154	3507	0.044	0.044		
P-19	168	505	22	12	185	3507	0.053	0.053	P-19	
P-19	165	597	21	14	209	3507	0.060	0.060	mean	0.0639
P-19	167	553	23	12	212	3507	0.060	0.060	std dev σ	0.0146
P-19	166	538	24	16	215	3507	0.061	0.061	+2σ	0.0932

Appendix 2. Test Data on Gravel

Experimental Data								Statistically Screened Data		
Method	Test Number	Flow Rate GPM	Extingushment Time Sec	90% time	Agent Used Gal	Area sqft	Application Rate gal/sq. ft.	Application Rate gal/sq. ft.	Screening Statistics	
P-19	163	250	61	26	254	3507	0.072	0.072	-2σ	0.0346
P-19	164	546	28	13	255	3507	0.073	0.073	count	11
P-19	159	250	63	52	263	3507	0.075	0.075		
P-19	183	543	47	29	425	5172	0.082	0.082		
P-19	161	250	70	39	292	3507	0.083	0.083		
UHPS	242	70	93	62	108	3507	0.031	0.031		
UHPS	255	95	120	80	189	5172	0.037	0.037		
UHPS	221	70	191	80	223	5172	0.043	0.043		
UHPS	235	66	140	82	155	3507	0.044	0.044		
UHPS	238	101	92	56	155	3507	0.044	0.044		
UHPS	237	100	96	80	160	3507	0.046	0.046		
UHPS	254	102	141	100	240	5172	0.046	0.046		
UHPS	239	101	106	60	178	3507	0.051	0.051		
UHPS	243	101	173	130	291	5172	0.056	0.056	UHPS	
UHPS	244	100	180		299	5172	0.058	0.058	mean	0.0577
UHPS	223	70	280	82	327	5172	0.063	0.063	std dev σ	0.0150
UHPS	234	69	203	220	232	3507	0.066	0.066	+2σ	0.0877
UHPS	236	99	143	98	237	3507	0.068	0.068	-2σ	0.0276
UHPS	222	70	300	73	350	5172	0.068	0.068	count	19
UHPS	240	101	141		238	3507	0.068	0.068		
UHPS	253	101	225		378	5172	0.073	0.073		
UHPS	224	70	328	83	383	5172	0.074	0.074		
UHPS	225	70	330	120	385	5172	0.074	0.074		
UHPS	241	71	254		302	3507	0.086	0.086		